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TREATMENT
OF
AIRPLANE WING COVERINGS

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The following publication, entitled "Treatment of Airplane Wing Coverings," is published for the information and guidance of all concerned.

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BY ORDER OF THE SECRETARY OF WAR:

PEYTON C. MARCH,
General, Chief of Staff.

OFFICIAL:

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The Adjutant General.

TREATMENT OF AIRPLANE WING COVERINGS.

The question of suitable material for airplane wing covering is one which was neglected for a considerable time even after the heavier than air machines had advanced to its present high state of development. Now, however, the question of a suitable material for a wing covering receives considerable attention, not alone from the makers and designers of aircraft, but from textile men as well, who see in aviation a new field for their product.

In the earlier days, all sorts of fabrics were experimented with, but silk and linen finally became the two main materials used. There were several reasons for this choice, but one of the chief influences was the way the fabric behaved on the application of the "dope," which was applied for the purpose of drawing the fabric up tightly to make a taut, drum-like surface, and possibly to reduce the skin friction of the material as it passed through the air. Silk is no longer used in this country, owing to the well-established fact that it deteriorates more rapidly after doping than other fabrics. Cotton fabric is gradually replacing other fabrics in this country and is giving satisfaction. The relatively high tensile strength of these materials for small weight was really the main determining factor in their choice.

REQUIREMENTS OF AIRPLANE FABRICS.

The general practice of to-day requires that the following properties be contained in an airplane wing covering:

(*a*) Relatively high tensile strength both in the warp and in the filling.

(*b*) High resistance to tearing as determined by several common methods.

(*c*) Low weight per square yard of the material.

(*d*) Less stretch in the filling threads than in the warp threads.

(*e*) The weave, texture, and finish of the fabric to be such as to permit of a good bond between it and the dope.

TENSILE STRENGTH.

This is required to be high because the yarns are in tension at all times during flight, and it is desired to have the minimum fatigue effect due to repeated or continued stresses in the material.

TEARING RESISTANCE.

The need for this is self-evident. In the event of a rupture or tear in the fabric it is desirable that the tear or rupture be kept its minimum size to preserve the contour of the wing section and to give every possible advantage to pilots.

LOW WEIGHT.

Low weight in an airplane wing covering is highly desirable. The fabric used at the present weighs from 4 to 5 ounces per square yard. The tendency is toward even lighter fabrics, and in view of experimental work already done it will not be surprising if a material weighing only $2\frac{1}{2}$ to 3 ounces is found to be suitable for some types of planes. Airplane cord fabrics, similar in construction to automobile tire cord fabrics, seem to be the reasonable line of development, and the general trend at the present is along those lines.

STRETCH.

The question of stretch is of greater importance than would at first appear. To emphasize this point, it is necessary to go slightly into details, but the question is of sufficient importance to warrant the digression.

To permit ease of handling and for the sake of production in its application, the fabric is applied to the wing with the warp threads parallel to the line of flight, and the filling threads running from rib to rib. The warp threads are parallel to the selvages and run lengthwise in the fabric. The filling threads are the cross threads. When the fabric is applied it is laced to every rib, which means that the filling threads are supported at intervals of 14 inches or less (usually much less), while the warp threads are supported only by the leading and trailing edges, so far as stretch is concerned. From the above, it can readily be seen that as long as the points of support of the filling threads are so much closer together than the warp threads it is necessary that their stretch be less if we would not introduce the added chance of fabric failure by repeatedly stressing the warp yarns beyond their elastic limit.

METHODS OF TESTING FABRIC.

In testing an airplane fabric to determine its physical properties, all tests are made under known and controlled atmospheric conditions of 65 per cent relative humidity at a temperature of 70° F. The following determinations are made:

(*a*) Threads per inch, in warp and filling.
(*b*) Weight in ounces per square yard.
(*c*) Stress-strain diagrams are plotted on an autographic tensile strength machine.
(*d*) Tearing tests by several methods.

From the nature of the determination, (*a*) and (*b*) of the above require no further explanation; (*c*) is used to determine the breaking load for the particular fabric, and the stress-strain diagram shows the relative stretch in the warp and in the filling of the sample.

There are two kinds of tears in general in an airplane fabric—one in which a hole has been punched as by a bullet, and the other where a flap protrudes in the air blast and has a tendency to tear back to the trailing edge. The conditions of the first are approached as nearly as can be in the laboratory by subjecting a punctured sample to known pressures, and measuring the pressure required to continue the original rupture, and the deflection of the fabric due to the application of this pressure.

The conditions of the second tear are approached by recording the actual pull in pounds required to continue the tearing.

PREPARATION OF AEROFOILS FOR FABRICS.

All aerofoil framework, and in fact all covered parts of an airplane having metal parts which come in contact with the doped fabric, should be wrapped with fabric to prevent rust from metal attacking fabric. If the trailing edge is to be hand sewed, it will be necessary to wrap it with tape if metal trailing edge is used. This will permit pinning the fabric to the wrapping in giving the cover its initial tension. Initial tension is explained more in detail further on in the pamphlet. The varnished parts which come in contact with doped fabric are protected by painting with a thin glue sizing.

APPLICATION OF FABRIC TO AEROFOILS.

There are two general methods of covering aerofoils with fabric, which are as follows:

(*a*) Strips of the fabric are cut sufficiently long to permit of their passing from the trailing edge over the top of the wing around the

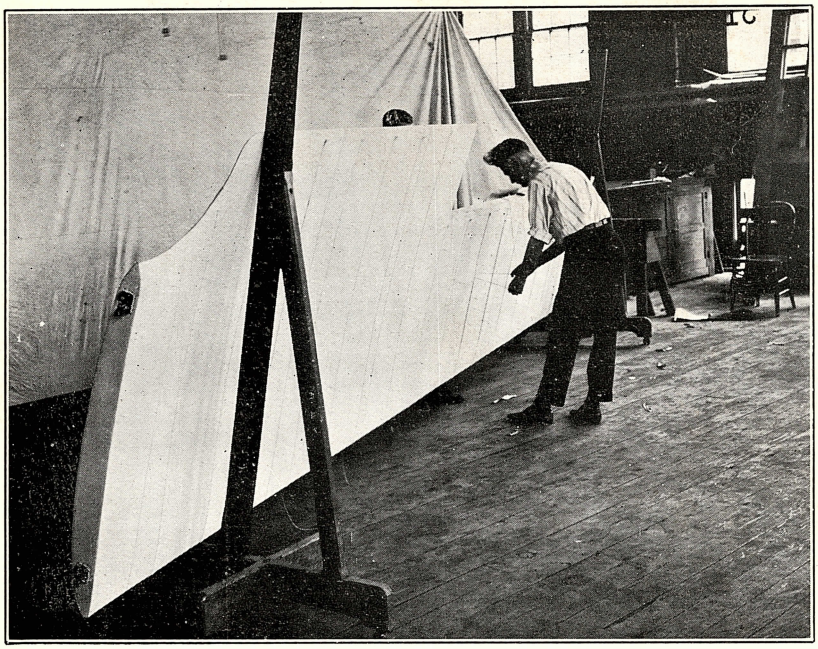
entering edge and back to the trailing edge. This is to avoid having a seam at the entering edge. A number of strips sufficient to completely cover the length of the wing are then sewed together. The cover in the form of a sheet is placed on the wing so that the opening in the cover will lie along the trailing edge. It is necessary next to give the covering its initial tension. Every fabric has its own critical tension, and the limits of this tension can only be obtained by actual experience with the different fabrics—e. g., there are more than a dozen different cotton airplane fabrics, and owing to the differences in construction or weaving, each fabric will have a different amount of stretch. As a general rule, the greater the stretch the tighter the fabric must be pulled for its initial tension. Unless this critical tension is known and given, the stretch in the fabric will be greater than the stretch in the dope, and as a consequence the machine will be "flying on the dope." The usual limits of the initial tension in standard airplane fabrics are from $1\frac{1}{2}$ to $2\frac{1}{2}$ pounds per linear inch. The cover is now ready to be sewed onto the frame by hand on all edges but the entering edge, which has no seam.

This method is slow, but fine work can be done when it is used. It is also the best method for use in experimental work.

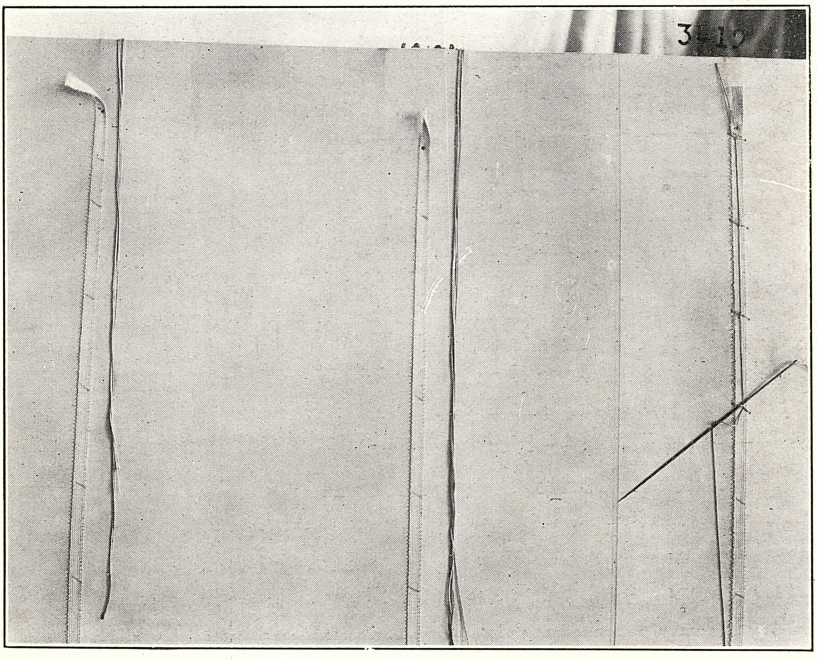
(*b*) The envelope method is cutting the fabric according to pattern and sewing it up by machine, leaving both ends open to permit it to be drawn onto the frame envelope fashion, and pulled up from both ends to secure greater initial tension. These open ends are temporarily tacked and then sewed by hand. When production is desired this is by far the best method to use.

METHOD OF OBTAINING INITIAL TENSION.

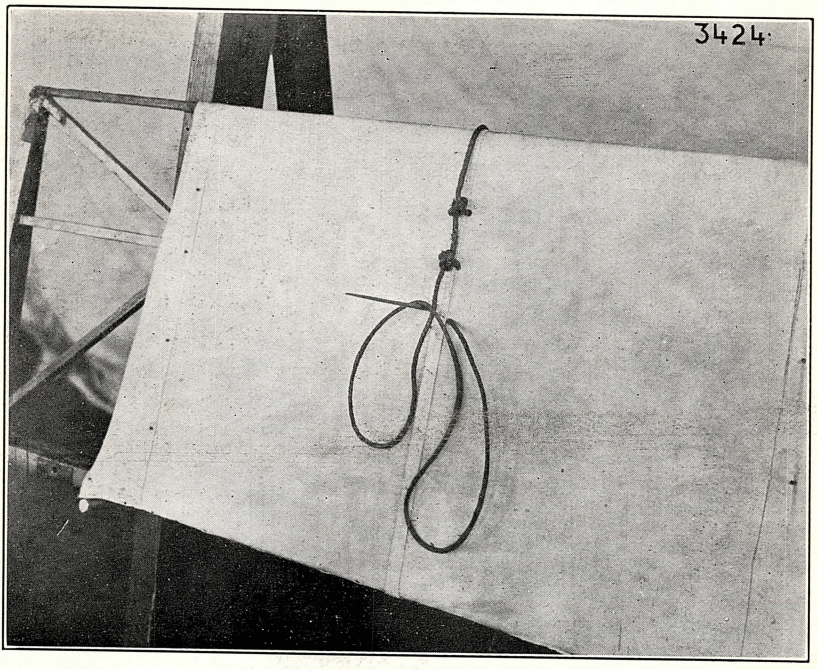
Temporary tacks are driven through the cover on the underside of the leading edge *at each seam only*. The wing is then turned topside up and the operator starts at the trailing edge to pull the cover gradually tighter from one end of the wing to the other. If a wooden trailing edge is used, tacks are used temporarily to retain the retention given by this hand pulling. If a metal trailing edge is used, the fabric is pinned to the tape wrapping. As the operator pulls up and tacks or pins, he folds under the raw edges of the fabric in the preparation for hand sewing. It is well to leave about one-fourth inch space between the two edges to be sewed so that the stitching will give a little additional tension. The importance of initial tension can not be denied, as it is one of the numerous factors in determining the amount of vibration in the wing covering during flight.



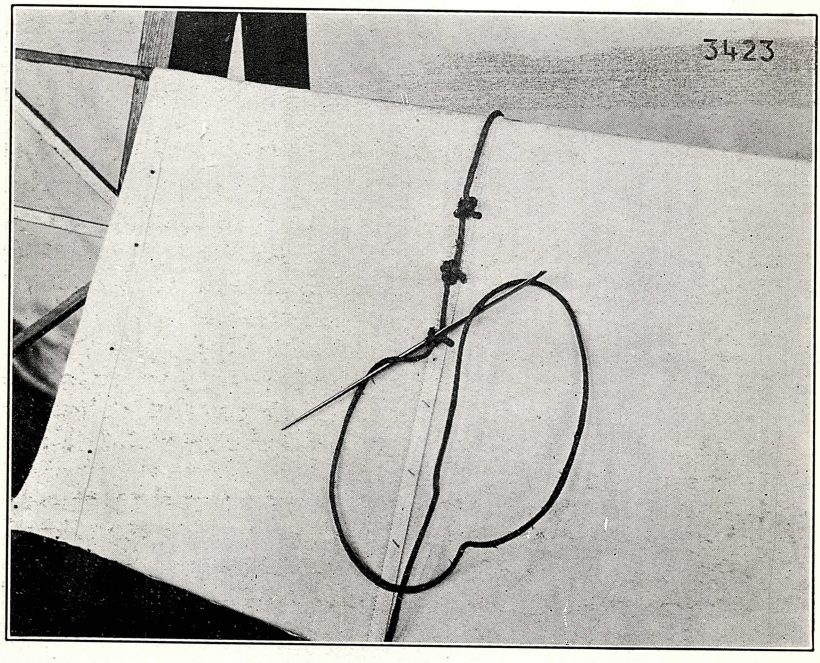
LACING RIBS, BOTTOM.



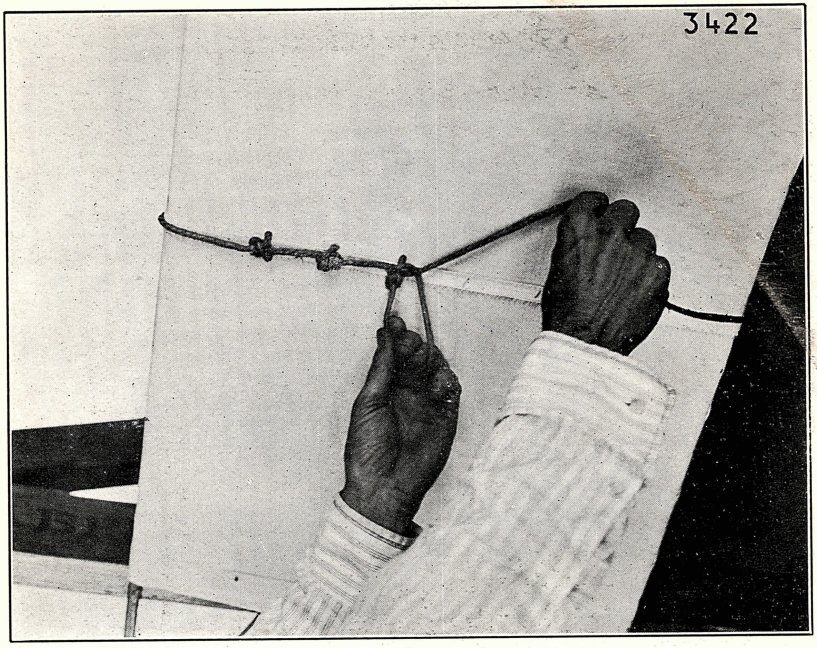
REINFORCING TAPE IN PLACE FOR LACING.



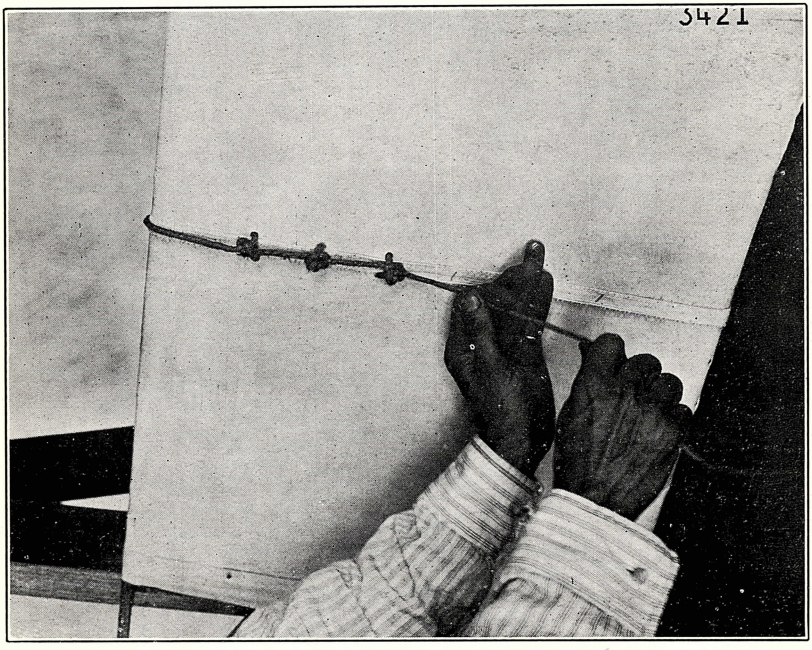
NONSLIP SEINE KNOT, FIRST STEP.



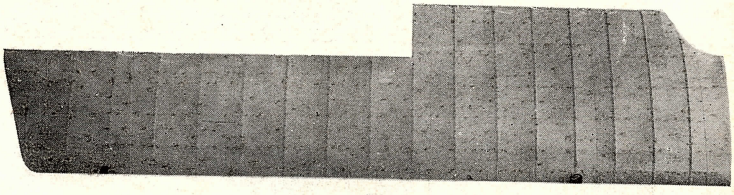
NONSLIP SEINE KNOT, SECOND STEP.



NONSLIP SEINE KNOT, THIRD STEP.



NONSLIP SEINE KNOT, FINISHED.



WING READY FOR DOPING.

LACING THE FABRIC TO AEROFOILS.

Lacing is a very necessary operation, as the attachment to each rib affords a point of support for the fabric, lessening the effect of vibration. With the present-day theory of airplane fabric design, it is important and, in fact, necessary that the fabric be laced to each rib.

The method of fastening to the rib is as follows: Tape the width of the rib cap strip is placed onto the rib and over the fabric, and is held in place during the lacing by tacks which are withdrawn when the lacing is completed. The lacing extends along the entire rib, starting at the trailing edge and finishing as near the entering edge as possible. At 2¼-inch intervals on the inner bay of each wing and at 4-inch intervals for the balance of the wing (this is because the vibration of the fabric is greatest in the air blast of the propeller), the lacing is passed completely around the rib from front to back and knotted in the front in a nonslipping knot, which gives a very secure connection and permits of the minimum vibration. The only satisfactory nonslipping knot is what is known as the "seine" knot. With the fabric so attached to all parts of an airplane, it is ready to be doped.

APPLICATION OF FABRIC.

Attention is directed to an air-service specification No. 24, 108–B, which contains an outline of the standard practice of fabric application to airplanes. It is slightly more general than this pamphlet, but it should be at hand in all fabric work. A later paragraph tells how to secure it.

DOPE AND DOPING.

To a certain extent the purpose of airplane dope is to produce an impervious and smooth coating on the fabric, but its most important function is the production of a satisfactory tautness. The mechanism of this action is twofold. There is a shrinkage of the dope film; not a shrinking of the fabric in the ordinary sense, but a powerful contraction on the part of the dope film during the process of drying. If the initial tension is right, the dope does not affect the fabric only in so far as it lessens its flexibility. The wing cover could not become tighter from doping without exerting a greater pull on the wing framework. Experiments have conclusively proven this not to be the case. In addition to this, films of dope and strips of doped fabric stretch very much less than strips of undoped fabric under a

given tension, provided this tension is below the elastic limit of the dope. Therefore, doped fabric is very much less deformed by the pressure exerted upon the wing during flying than undoped fabric would be.

The fundamental constituent of the dope is a film-forming gelatinous substance which has been cellulose nitrate or cellulose acetate in all commercial dopes. Cellulose nitrate, which is also the base of ordinary celluloid, is a very highly inflammable material, and its use has been prohibited on military airplanes in favor of less inflammable, although more expensive, cellulose acetate.

The film-forming constituent is dissolved in a volatile solvent, of which acetone is the type. Since certain nonsolvents, such as benzol and alcohol, are cheaper than the solvents, and since a considerable proportion of them may be added without injurious effect, dopes usually contain such materials which are called "diluents." In order to prevent "blushing" or whitening during the application of the dope, a "high boiler" is necessary. This is a solvent liquid whose boiling point is considerably higher than that of water. Finally, there is necessary to produce a durable dope, a certain proportion of plasticizers. These are substances of low volatility, not necessarily solvents, which soften the film and make it tougher. A high boiler will usually also function as a more or less temporary plasticizer, but its primary function is the prevention of "blushing."

One of the greatest enemies of good doping is high humidity. If water is added to a dope solution, a point is reached at which the film-forming constituent is precipitated from solution in an opaque porous form of little strength. During the drying of dope, the rapid evaporation of volatile solvents produces a marked cooling effect, and there is a great tendency for water to be absorbed from the atmosphere. If this absorption reaches a sufficient amount, precipitation takes place with the formation of white areas in which the dope very soon disintegrates. A high boiler counteracts this because it evaporates more slowly than water does and keeps the film-forming constituent in solution until the water has an opportunity to evaporate. Cellulose acetate is a material of more recent development than cellulose nitrate, and there has been some difficulty in developing suitable "high boilers." For this reason, some of the earlier acetate dopes contain no "high boilers" at all and can be applied without "blushing" only under conditions of very low humidity. This accounts for a large part of the prejudice against ace-

tate dope, but more modern examples are quite as satisfactory as the nitrate dopes in this respect. The matter of adding "high boilers" in the proper quantity is fully and completely taken care of in the manufacture of the dope and under no circumstances should any attempt be made at flying fields or factories to affect the quantity of "high boilers" present in the dope. A careful consideration of the matter of relative humidities during the various stages of application of fabric and dope will furnish the proper solution of difficulties due to "blushing." In any case, very great care should be taken to keep the humidity as low as possible; in a closed building by increasing the temperature over that existing outdoors. In particular, the fabric before doping should be kept at the same temperature and humidity as that in the doping room. Temperature 70° to 80° F. Relative humidity 50 per cent to 60 per cent. The reason for this is, if the relative humidity in the covering room be higher than the relative humidity in the doping room, the fabric will give off moisture until it comes to equilibrium with the moisture in the doping room. This would mean a slacking of the fabric. The ideal condition would be for the relative humidity in the covering room to be slightly lower than that of the doping room. This would permit the fabric to become slightly tighter in coming to equilibrium with the moisture in the doping room.

The tautness of the doped fabric depends, to some extent, upon the weight of the dope film applied. With a satisfactory dope, however, suitable tautness should be obtained in not more than five coats and the weight required should not exceed 2.75 ounces per square yard.

Since the solvents in use in dopes are highly volatile, it is important to keep dope in tightly closed containers, otherwise the concentration due to evaporation may easily produce a solution too viscous to be applied by a brush.

Both cellulose acetate and cellulose nitrate undergo a serious deterioration when exposed to sunlight, becoming brittle and finally completely disintegrating. This deterioration is little, if any, lessened by a transparent varnish, but a great deal of protection is afforded by a pigmented coating, which may be either oil enamel or a pigmented dope. The pigmented dopes have the advantage of very much more rapid drying; but in any case, the important thing in selecting a colored coating for airplane wings is a very high flexibility. "House paints" or automobile body enamels go to pieces in a very short time.

APPLICATION OF DOPE.

The proper application of dope to an air foil is possibly easier to explain than it is to actually perform. Temperature and relative humidity must be considered both at the time of covering an air foil with fabric and at the time of the application of dope, if the coating of dope is to remain clear and if "blushing" of dope is to be prevented.

The usual procedure is to apply five coats of an "acetate" dope by hand, waiting a half hour or more between coats to permit good drying. This will give a good bond between the dope film and the fabric, and the results of this method in practice have been eminently satisfactory.

One of the most satisfactory methods of dope application hit upon by actual experiment and results watched during use is to apply the first coat in the thinnest possible layer, hardly more than a general dampening of the fabric, and four or five subsequent layers to be of the usual thickness. This seems to establish a better bond between the fabric and the dope film, and affects the tear resistance of the doped fabric less than any other method which has been tried.

The theory of the bond between fabric and dope film has come in for considerable discussion recently, and it is not the function of this pamphlet to specifically declare what the correct theory is, but it is "apropos" to say that partial or complete penetration of dope into the fabric is not desirable in that it affects the fabric's physical properties more than a union between the dope film and the surface of the fabric. This effect is obtained by the application of the extremely light first coating, as previously explained, which forms a base for the other coats and prevents excessive penetration.

STORAGE OF DOPES.

The storage of dope offers little difficulty when it is in steel containers. These containers should be protected from too high temperature, which might develop undue pressures. Wooden barrels suffer from a tendency to dry out and become porous to the vapors of the solvents. In order to avoid serious deterioration of the dope, they should be kept in a cool, dry place. Barrels or steel drums of dope if kept in the open, should be covered with tarpaulin to protect them from the sun and the weather. Large quantities have been spoiled in the past because of lack of this protection.

SUMMARY OF PHYSICAL PROPERTIES OF AIRPLANE TEXTILES.

It is thought advisable in this pamphlet to summarize the physical properties of the various textile materials used on an airplane, but first several terms will be defined for a better understanding of the tabulated data.

Warp (*threads*).—The threads which run lengthwise of the strip of cloth as it comes in the bolt; the threads which are parallel to the selvaged edges.

Filling (*threads*).—(Sometimes called weft.) The threads which run across the fabric, i. e., from selvage to selvage. The filling threads are the threads which are carried over and under the warp threads by the shuttle at the loom.

Sizing.—Materials, such as starch, used to condition the yarns to facilitate the weaving of the cloth.

Count.—The number of threads per inch of cloth is designated as the count.

Ply.—Ply is the term used to express the number of yarns used to make up the thread. The size of the yarn is indicated by a figure before the word "ply."

Mercerization.—Mercerization is the treatment of cotton fabric or thread by momentary immersion in a hot dilute solution of caustic soda. It is this process which gives greater strength and luster to the fabric. Reduced stretch is also obtained by the American system of mercerization.

Staple.—The length of the individual fiber is called staple.

These terms are used in the following table:

Table of requirements for textile materials used in airplanes.

Abbreviations: W.=Warp; F.=Filling.

Specification No.	Name or designation.	Used for.	Raw material.	Structure of yarn.	Count.	Tensile strength (minimum).	Weight under normal moisture conditions (maximum).	Sizing (maximum allowed).	Remarks.
16004-A	Grade A cotton airplane fabric.	Combat and high-powered airplanes.	Cotton of at least 1.5-inch staple.	60–2 ply	80–84 in both W. and F.	80 pounds per inch W. and F.	4.5 ounces per square yard.	3.5 per cent	Unbleached. Yarn mercerized under tension.
16005-A	Grade B cotton airplane fabric.	Low-powered training planes.	do	80–3 ply	68–72 in both W. and F.	73 pounds per inch W. and F.	do	do	
16028	3-ounce special	High-speed planes.	do	60–1 W., 60–2 F.	80–88 W., 90–92 F.	38 pounds W., 100 pounds F.	3.5 ounces per square yard (maximum).	2.5 per cent	
16003-B	Grade A linen airplane fabric.	Combat and high-powered airplanes.	Unbleached flax.	Single	90–105 in both W. and F.	75 pounds per inch W. and F.	4.5 ounces per square yard.	3.5 per cent	British made.
16003-B	Grade B linen airplane fabric.	Low-powered training planes.	do	do	60–90 in both W. and F.	65 pounds per inch W. and F.	do	do	
16027	Special reinforcing tape.	Underlacing cords over fabric on top of aerofoil ribs.	Cotton	Variable	14 for width, 30 in F.	180 pounds for its width.	Variable	do	½ inch wide. Strength is much greater in W. than in F.
	Linen finishing tape.	Overlacing and reinforcing tape.	Linen fabric	Single	Variable	Variable	do	Similar to grade A or B linen.	2¼ inches wide, ¼ inch on each side frayed out. British made.
	Surface tape	do	Mercerized cotton airplane fabric.	Similar to grade A or B cotton.	Similar to grade A or B cotton.	Similar to grade A or B cotton.	Similar to grade A or B cotton.	Similar to grade A or B cotton.	Pinked (scalloped) edges. 2½ inches wide outside pinks; 3¾-inch tape, similar to this, for box ribs.
16018-A	Serving tape	Wrapping metal parts, joints, or splices, where linen cord is not specified.	Cotton	2-ply W. and F.	Minimum 48 in W., 60 in F.	1⅛ inches, 80 pounds; ⅝ inch, 65 pounds for width.	1⅛ inches, 1⅞ pounds per 144 yards; inch, 14–15 ounces per 144 yards.		In two widths, 1⅛ inches and ⅝ inch.
16017-A	Heavy linen thread.	For lacing fabric to aerofoil framework.	Natural-color linen.	9 strands right-hand twist.		85 pounds when tested double.	Minimum of 500 yards to the pound.		
16020	Special cotton cord.	do	Sea Island, Egyptian, or Pima cotton of at least 1.5-inch staple.	20–3 ply, 3 ply, 3 ply.		do	Minimum of 550 yards to the pound.		Special twist; high fray resistance.
16016	Light linen thread.	For hand sewing of seams.	Natural-color linen.	30–3 ply		14 pounds when tested double.	Minimum of 2,800 yards to pound.		Not to be used for machine sewing account of size.
16015	Silk thread	For machine sewing of seams.	Pure natural silk	3-strand left-hand twist.		3 pounds, tested single.	Minimum of 1 ounce per 1,000 yards.		For machine sewing; commonly known as size A sewing silk.

ORDERING MATERIAL.

When ordering material for use at an Air Service flying field, it will greatly facilitate matters if the order always contains a description of the material as indicated in the above table under "Name or designation," together with the Air Service specification number, also tabulated above.

When ordering fabrics, it is also well to bear in mind that the cotton fabric, grade A, specification No. 16004–A, should be used in preference to the linen at all times for the reasons that, first, the performance of the cotton fabric, with the standard method of application as outlined in specification 24108–B, is equal to the performance of the linen fabric, and second, the cost of the cotton fabric is less than the linen, and third, the supply of cotton for airplane fabric is practically unlimited.

INFORMATION CIRCULARS.

The Engineering Division of the Air Service at Dayton, Ohio, issues at intervals circulars for the information of all whose work is concerned with the Air Service. These circulars contain information on motors, planes, equipment, and material. It is suggested that all flying fields keep a file of these information circulars which will keep them informed regarding current practice.

Information circulars are sent to all flying fields at the time of issue. Missing or back numbers can be obtained by writing to the Technical Data Section of the Engineering Division, Dayton, Ohio.

SPECIFICATIONS.

All materials used in airplane construction and repair are covered by a specification. The specifications for textile or other materials, if not already on hand, can be obtained from the Standards and Specifications Section of the Engineering Division, at Dayton, Ohio. It is strongly recommended that those concerned with the manufacture or maintenance of airplanes thoroughly acquaint themselves with the specifications for these airplane materials. In the past not enough attention had been paid to requirements as indicated by the specifications, but this lack of attention was probably due to the urgency of the situation. In the future, strict conformance with these specifications will be required.

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